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Big Data and AI in Combating Oil Theft and Resource Management

N. E. Bello
Kano State Polytechnic, Kano, Nigeria
G. Nwosu
Federal Polytechnic, Ado-Ekiti, Nigeria

Abstract:

This study investigates the transformative role of Big Data and Artificial Intelligence (AI) in combating oil theft and enhancing petroleum resource management, with a specific focus on Nigeria. Oil theft poses significant economic, security, and environmental challenges, undermining government revenues, corporate profitability, and national stability. By leveraging Big Data analytics from sensor networks, transactional records, and satellite imagery, theft patterns can be detected early, enabling proactive interventions. AI techniques—such as machine learning, neural networks, support vector machines, and anomaly detection—facilitate predictive maintenance, resource optimization, and automated decision-making in oilfield operations. The integration of these technologies creates a synergistic effect, allowing for real-time monitoring, anomaly identification, and predictive analytics across the petroleum supply chain. Emerging innovations including the Internet of Things (IoT), blockchain platforms, and remote monitoring systems further enhance transparency, traceability, and security. However, challenges persist regarding data integration, scalability, and ethical considerations such as privacy and fairness. The study emphasizes the need for supportive policies, regulatory cooperation, and international collaboration. Overall, Big Data and AI present robust, data-driven solutions for mitigating oil theft, optimizing resource allocation, and promoting sustainability in the petroleum industry.

Keywords: Big Data, Artificial Intelligence, Oil Theft, Resource Management, Nigeria, Predictive Analytics, Blockchain

1. Introduction

The study explores the transformative impact of Big Data and Artificial Intelligence (AI) on the petroleum industry, focusing on their potential to combat oil theft and enhance resource management. Big Data analytics can process extensive datasets from sensor logs, transactional records, and social media feeds, enabling early detection of theft patterns and facilitating crime prevention. AI techniques, encompassing neural networks, support vector machines, and random forests, support predictive maintenance, anomaly detection, and automated decision-making, thereby aiding in theft reduction and operational optimization. The global challenge of oil theft induces significant revenue losses and environmental risks, necessitating innovative technological interventions for mitigation and sustainability promotion. Digital oil fields leverage sensor networks, communication systems, and integrated data centers to collect and analyze heterogeneous data, supporting rapid strategic responses. AI algorithms assist in pattern recognition, time series analysis, knowledge discovery, and supervisory control, thereby enhancing production optimization, performance monitoring, and failure prediction across drilling and production phases. The complementary integration of Big Data analytics and AI techniques facilitates proactive theft detection, informed decision-making, and adaptive resource deployment. Recent advancements in Internet of Things (IoT) devices, blockchain platforms, and remote monitoring systems further augment transparency and operational control. Effective application of these technologies requires supportive policy frameworks, regulatory alignment, and attention to data privacy and ethical considerations. Empirical demonstrations underscore the potential benefits of such integrated approaches, encouraging continued exploration of emerging technologies and strategic planning for their deployment in oil and gas sector governance (Lopes D'Almeida et al., 2022) (Wang et al., 2024).

2. Understanding Oil Theft

Global oil demand is expected to grow by 10% from 2020 to 2050 (Lopes D'Almeida et al., 2022). Oil theft constitutes a severe security threat that significantly reduces legitimate supply and negatively impacts governments, corporations, and the general population. Its causes include diverging locations of oil wells and refining centers, ineffective surveillance due to infrastructure difficulties, and corruption. Oil theft primarily occurs through pipeline tapping by criminal groups (Hua Tan et al., 2016).

Oil theft—also termed illicit or illegal oil bunkering or oil bunkering—is the unauthorized removal of petroleum products from legally sanctioned vendors or government entities. It represents the deliberate intervention in petroleum production, supply, and distribution to divert and sell hydrocarbons for unauthorized commercial benefit. Oil thieves operate by installing secret gauges within properties to monitor inventory levels, identifying any irregular drops indicative of theft. Historically, acquired oil may be transported to neighboring countries for illegal transshipment. Recently, complex illicit refining networks have emerged, enabling the on-site conversion of crude oil and other derivatives to products such as gasoline, diesel, kerosene, and even jet fuel. These illicit activities impose a substantial financial burden on developing countries, resulting in heavy losses for governments and companies worldwide.

2.1. Definition and Scope

Big Data and Artificial Intelligence (AI) are rapidly emerging techniques for improving oil theft detection and oil resource management. Data from numerous sources is collected and analyzed with the aid of Big Data analytics to uncover abnormal patterns that could indicate asset damage or theft, enabling operators to take timely action in preventing these occurrences. AI algorithms extract informative features from the data, eliminating redundancies and ensuring the employment of the most vital information. Machine-learning algorithms further help in analyzing the data to model the potential risk levels and threat sources. However, several challenges remain for the full utilization of Big Data and AI for oil theft detection and prevention. Further innovations and implementation strategies are necessary to bridge these existing gaps.

Oil remains a vital commodity that powers the world. Its increased availability and proper management ensure financial and energy security experienced by nations. Unfortunately, there are many associated risks and problems impeding the attainment of this goal. Wasteful usage, inefficient exploration and production, pollution, and theft have resulted in shortage and unavailability at critical periods. Proper monitoring and management of oil can improve supply and hence reduce financial and resource waste. In particular, the issue of oil theft has become more prevalent worldwide following the recent conflicts and skirmishes in oil-producing regions. The oil theft operation comprises the illegal extraction of crude oil from transit systems and the resale of the stolen quantities for commercial purposes. It is sometimes referred to as Bunkering, Poaching, or Poaching. The illegal tapping and siphoning of oil resources have continued to have a widespread impact, not only on governments but also on other stakeholders. Because of its illegal and covert nature, oil theft remains a challenge to monitor and control effectively.

2.2. Historical Context

The theft of crude oil and refined products has evolved into a critical challenge affecting the profitability of oil and gas companies and depriving nations of substantial revenue. Globally, theft poses risks to the safety and quality of petroleum products and is a significant source of environmental pollution (Lopes D'Almeida et al., 2022). Consequently, security, safety, and environmental risks have skyrocketed as a direct result of illegal oil bunkering, underscoring the urgent need for enhanced and real-time monitoring of oil pipelines to curb widespread theft.

Big Data technology offers an effective mechanism for large-scale data processing, rapidly mining out hidden and valuable data. The datasets considered encompass sensor-generated data, transactional data recorded in oil depots, geographical data of the pipelines, and customer data. Various analytical methods are essential for large-scale oil theft detection; notably, widely used techniques such as cluster analysis, outlier detection, and correlation analysis can unearth pertinent knowledge that helps locate potential theft locations, identify impeded flow-meter sensors, and discern illegal entities that siphon refined products and crude oil. Additionally, Business Intelligence systems assist petroleum marketing companies in achieving greater efficiency and monitoring supply chains to combat existing oil theft practices (Hua Tan et al., 2016). Subsequently, AI methodologies can predict, sense, and assess instances of oil pilferage, pinpoint probable theft sites, and ascertain the outcomes of diverted oil (Wang et al., 2024).

2.3. Impact on Economies

Oil theft, also known as oil bunkering or illegal tapping, involves the unauthorized siphoning or pilfering of oil or petroleum products from pipelines, storage facilities, or transportation systems. Beginning as early as the 1970s, oil theft has evolved extensively with technological advances that facilitate easier access and distribution. This illicit activity yields serious economic consequences, siphoning revenues from governments and legitimate companies alike and adversely affecting the economies of impacted countries. As a major hindrance to petro-economies and a catalyst for violence and unrest, depleting crucial financial resources for infrastructure and development, oil theft demands urgent commitment to investigate, control, and mitigate its effects (Lopes D'Almeida et al., 2022).

3. The Role of Big Data

Big Data has become a critical tool against oil theft and in managing oil and gas operations (Hua Tan et al., 2016). For oil theft detection, source materials include pipeline and storage-tank sensors, transaction records, social media posts, spreadsheets, and historical archives. Subsequent analysis processes incorporate diverse methodologies and detection techniques. More generally in oil and gas fields, data influx is seemingly continuous as digital oil fields develop. Increasingly, companies construct sensors, communications systems, and data centers. Altogether, the collected data—often heterogeneous and from various sources—undergo rapid, seamless transmission and recording, followed by appropriate algorithmic scrutiny and utilization (Lopes D'Almeida et al., 2022).

3.1. Data Sources and Types

Data sources for analyzing the detection of oil theft span various formats, from sensor data to transactional records (Hua Tan et al., 2016). Sensors, in particular, are essential for real-time monitoring of parameters, such as quality, to reduce operational risks: for example, to limit the number of screw turns during screw assembly. Big Data solutions also provide early warning mechanisms for external risks, like weather or epidemics, which could disrupt supply chains. Integrating risk awareness into overall supply chain management enhances responsiveness and resilience.

3.2. Data Analytics Techniques

Data analytics techniques are essential for the successful implementation of Big Data and AI applications. The efficiency of these techniques greatly influences the overall effectiveness in addressing oil theft and resource management concerns. Applying the most suitable algorithms to a given problem can yield additional benefits, yet the choice of technique depends on various factors and domain knowledge.

Data mining and machine learning represent prominent data analytics methods employed to extract information from large datasets. These techniques often accompany Big Data and AI applications in relevant fields. Data mining constitutes the process of analyzing data from different perspectives, including visualization and summarization, to derive new and useful information. Big Data analytics refers to the range of quantitative and qualitative techniques used to obtain relevant insights from diverse, high-volume, dynamic, and often ambiguous data sources, all while permitting heterogeneous data processing (Hua Tan et al., 2016).

The fast-paced development of machine learning techniques enhances the ability to process and analyze data effectively and efficiently. By utilizing statistical, probabilistic, and optimization techniques, machine learning algorithms construct models from observed data; the resulting model is then applied to new data to perform specific tasks. Supervised learning methods use known, labeled data to build a classifier capable of organizing and labeling unknown data. Unsupervised learning methods group unlabeled data according to its inherent characteristics, facilitating subsequent analysis and interpretation. Semi-supervised learning combines both labeled and unlabeled data to construct data classifiers capable of handling unknown data. Recently, adversarial learning has gained attention for enabling models to learn from multiple scenarios simultaneously, thereby increasing the robustness of the learnt model. These techniques contribute significantly to the capability of Big Data and AI systems to detect oil theft and manage hydrocarbon activities on the Nigerian National Petroleum Corporation (NNPC) facilities, where both types of data are available (M. Salem et al., 2022).

4. Artificial Intelligence in Resource Management

Artificial intelligence (AI) constitutes an essential technology for combating oil theft and managing scarce petroleum resources. AI algorithms are applied in conjunction with Big Data analytics and other technologies to detect and ultimately prevent theft (Lopes D'Almeida et al., 2022). Machine learning algorithms analyze large data volumes, identifying patterns indicative of theft and irregular activity. Models trained on historical data encompassing theft events, production figures, and transactional records facilitate accurate anomaly detection and risk forecasting (Wang et al., 2024). The effective application of AI requires comprehensive, high-quality data inputs to enable supervised or unsupervised learning of pertinent operational behaviors, thereby enhancing identification capabilities and response efficiency. When integrated with Big Data analyses, AI constitutes a robust approach to secure supply chains and optimize resource utilization.

4.1. AI Algorithms and Techniques

Artificial Intelligence (AI) algorithms and techniques often build upon Big Data research and analytics, enhancing current approaches and enabling further advancements. AI's predictive capabilities allow for forecasting specific types of failures or behaviors, offering superior guidance compared to standard data-mining and analysis methods (Lopes D'Almeida et al., 2022). Several algorithms demonstrate significant potential for effective analysis. For example, pattern recognition excels at learning and interpreting regular activity patterns, detecting anomalies that suggest theft. Outlier detection algorithms further assist in identifying unusual behaviors. Time series analysis tools extract trends and highlight departures from expected patterns. Clustering techniques uncover similarities in events or locations, facilitating investigations by pinpointing comparable instances. Machine learning—a subset of AI—employs both supervised and unsupervised methods to discern patterns and provide insights into potential oil theft, enhancing predictive and preventive measures.

4.2. Predictive Analytics for Theft Prevention

The oil and gas sector is undergoing profound stress owing to illegal activity including the stealing of crude oil coupled with a growing paucity of domestic energy sources. Predictive analytics has the potential for combating theft through automated analysis of large volumes of seismic, acoustic, flow, pressure, and other time series sensor data using state-of-the-art machine learning (ML) techniques. Big Data and Artificial Intelligence (AI) techniques are particularly useful for detecting stolen oil among legitimate purchases based on information collected from trucks, terminals, and burial wells. The industry is equipped with a high number of sensors that concurrently measure a large number of parameters. Datasets comprising these high precision data are therefore readily collected. Several parameters affect the final price of crude oil and it is vitally important that ML models designed for the prediction of the theft have a broader understanding of the many complex correlations between these different parameters. ML models would help policymakers and Governmental organizations to efficiently indicate which areas require the deployment of enhanced oil theft prevention schemes while Big Data techniques would permit quicker and more accurate data acquisition and analysis (M. Salem et al., 2022). Guided wave sensors may be deployed for the prediction of transfer line corrosion in upstream hydrocarbon production operations (Hua Tan et al., 2016). A range of additional IoT sensors may be utilized to develop a digital model of a production facility for monitoring and control, redundancy validation and anomaly detection, security access, and personnel safety. Such sensors may measure pressure, chemical levels, corrosion rates and temperature.

4.3. Machine Learning Applications

Machine learning (ML) plays a key role in the petroleum industry by enabling more informed decisions through advanced data analytics applied to real-time production parameters (M. Salem et al., 2022). It addresses uncertainties encountered in exploration and production activities by replacing traditional models. Algorithms are trained to analyze diverse datasets relevant to drill bit diagnostics, well-log interpretation, reservoir simulation, seismic pattern identification, history matching, porosity and permeability prediction, PVT analysis, production optimization, and performance evaluation. Provenance management of ML models is essential within upstream processes, as it supports quality control, accuracy verification, repeatability of outcomes, and transparency (Thiago et al., 2020). Automating failure detection, predictive analytics, and decision-making through ML transforms conventional workflows into data-driven approaches that increase efficiency and reduce costs during the entire lifecycle of oil field activities.

5. Integration of Big Data and AI

Big Data and Artificial Intelligence (AI) are increasingly regarded as crucial technologies for curtailing oil theft and other forms of illegal resource extraction, as well as for the management of oil resources once these activities have occurred. The integration of AI and Big Data can enhance resource exploitation and improve safety in complex and uncertain environments.

In the upstream segment of the oil and gas industry, data-driven AI technologies and machine learning facilitate high-precision reservoir prediction and real-time monitoring, enabling intelligent interaction with the physical environment (Lopes D'Almeida et al., 2022). In the midstream and downstream stages, the integration of AI and Big Data enhances decision-making, management, and operational efficiency during transportation and processing phases. Furthermore, AI plays a significant role in improving oil field production by real-time optimization and forecasting, safety management, and failure detection. Challenges remain concerning the quality and quantity of data, alongside issues related to interpretation and resource limitations. Consequently, the development of AI and Big Data technologies will continue to foster innovation, thereby refining oilfield exploration and exploitation.

The combination of sensor data, transactional data, operational logs, and external open data provides comprehensive insights into oilfield operations. The establishment of integrated data platforms, supplemented by analytics techniques such as machine learning and natural language processing, allows organizations to process diverse data types. Tools like visualization, statistical modeling, and graph analytics support query and analysis, facilitating the detection of theft and pilferage at every step of the supply chain (Wang et al., 2024). Single techniques, whether AI or Big Data, have limited capabilities; however, when integrated, their capabilities complement each other, producing a synergistic effect that enhances the detection and identification of anomalies related to oil theft, pilferage, fires, spillages, and leakages. Current efforts focus on integrating these technologies, highlighting their tremendous potential for the development of the oil and gas industry.

5.1. Synergistic Effects

The vast amounts of data generated during the production, transportation, and trading of petrol and petrol-related products can be integrated with artificial intelligence for more effective monitoring and management. Employing AI can significantly contribute to the control of oil theft by enabling the analysis of large datasets. Big Data lays the groundwork, while AI extracts value from the processed information. The sources of Big Data in the context of petrol production and management are diverse: sensor-generated data provides real-time monitoring of tanker locations and volumes; transactional and financial data shed light on spending patterns and potential misuse of funds; structural data records pipeline layouts, corridors, and pressure levels; and smart sensor data detects leaks, unusual pressure, and theft.

Despite the benefits of Big Data for loss prevention during production and transit, its capabilities have certain limitations. Artificial intelligence can help surmount these challenges by leveraging Machine Learning for pattern recognition and classification, as well as Deep Learning for enhanced prediction accuracy. These technologies detect suspicious tanker movements, dubious purchase patterns, and anomalies in pipeline pressure. The introduction of IoT devices—allowing remote monitoring and control of pumps—alongside smart sensors, data from the Nigerian National Petroleum Corporation (NNPC), and blockchain applications for ensuring transparency and traceability, represents a holistic integration of AI and Big Data designed to address the multilayered problem of oil theft.

5.2. Challenges and Limitations

The application of Big Data and AI in combating oil theft and optimizing resource management faces several challenges. Accurate data integration and efficient extraction remain critical issues. Integrating massive data from heterogeneous sensors, IoT devices, and other sources is complex in terms of scalability and feasibility (Jani, 2016). The continued increasingly large data from upstream operations like exploration and production add to the problem. Risk analysis of voluminous data remains challenging because of the number of concurrent factors and a comprehensive assessment is needed that considers risk metrics, decision criteria, and subject-oriented risk characterization. For Big Data growth management engaging a third party can be used for the storage on the cloud. This is disadvantageous in terms of transfer rate, bandwidth, and the security of the data. Intelligent cloud computing, low power fog computing, and broad edge computing platforms can provide a crucial support to oil-petroleum industry in performing Big Data analysis from storage to processing to visualization. Another challenge for Big Data is the complexity and uncertainty-based low accuracy of the decision-making systems. Even so, developing Intelligence systems improve the decision-making process in domains of Big Data.

5.3. Future Prospects

While the combined application of Big Data and AI significantly enhances oil theft detection and prevention (Lopes D'Almeida et al., 2022) , further opportunities exist to refine these approaches. Additional factors and entities—namely contractors, dealers, and agencies—contribute to unlawful oil activities, suggesting an expanded, multi-source analytical framework. Advancements in vehicle monitoring aboard major highways may reinforce pipeline surveillance systems. Continuous Big Data acquisition and analysis of existing pipeline networks enable the development of investigative profiles, while predictive analytics facilitate identification of emerging hotspots and extraction of complex insights (Wang et al., 2024). Incorporating missing data variables has the potential to improve data quality, reduce noise, and elevate detection accuracy. Ultimately, enhancing early detection capabilities serves to safeguard stakeholder assets, resource management, and national revenue streams. The strategic integration of AI with Big Data thus presents a robust platform for optimizing theft detection and resource management (Hua Tan et al., 2016).

6. Technological Innovations

Technological innovations including the Internet of Things (IoT) and smart sensors readily complement Big Data and artificial intelligence as practical instruments for eradicating oil theft and managing petroleum resources. Remote monitoring affords immediate control of petroleum infrastructures. Additionally, blockchain applications to oil-tanker services guarantee information transparency and transaction traceability.

6.1. IoT and Smart Sensors

The emergence of the Internet of Things (IoT) underpins the concept of Smart Sensors, Digital Twins, and the development of smart cities. The successful implementation of these ideas depends on the continuous progress in sensor technologies, which progressively extend their functions from merely sensing environmental parameters to playing a decisive role in processing data locally at the sensor level. Further, IoT and Smart Sensors reduce operator involvement by enabling the lower-level processing network to collaborate in decision-making. The design of Smart Sensors must incorporate a compact sensory system, a controlling central processing unit, dedicated communication functions, and decision-making algorithms, including root-cause analysis. Current developments20 highlight the efforts in delivering smarter devices capable of continual operation through advanced energy scavenging, high-end processing, and early failure prediction.

6.2. Blockchain for Transparency

Blockchain technology offers a method to record data about oil transfers in an immutable, verifiable way that multiple parties can access. Protocols can automatically trigger loan repayments and other payments via smart contracts. Securing and managing participants' data using blockchain technology enhances procurement processes in the oil supply chain. The upstream flow of the supply chain involves transactions and smart contracts. The conventional supply chain with modern Internet of Things (IoT) systems enables real-time monitoring and data security but faces challenges such as lack of trust, third-party interference, inability to monitor the entire supply chain, absence of encryption, and disparate legal jurisdictions. The SmartOil framework uses a private blockchain architecture that combines permissioned and consortium blockchains to ensure only trusted entities access the network, thereby providing end-to-end visibility. IoT devices collect data to keep track of products and automate smart contract execution (Bahalul Haque et al., 2021).

6.3. Remote Monitoring Technologies

A combination of artificial intelligence (AI), remote monitoring, the Internet of Things (IoT), and blockchain can address fraud and theft within the oil supply chain. The integration of ByteDance's enterprise blockchain DathChain, AI, and IoT technologies enables a secure and tamper-proof framework for supply chain management (TOMA & POPA, 2018). The employment of VTOL-type Unmanned Aerial Vehicles (UAVs) offers a unique, cost-effective approach for monitoring stripped and exposed pipelines remote from urban centers or active petroleum storage terminals (Idachaba, 2014). Initially, these VTOL UAVs track a pipeline area of interest using route navigation and waypoints defined within a Geographic Information System (GIS). The platform ventures beyond line-of-sight, remaining at a safe distance to avoid adversary recognition, and transmits the video feed to an unmanned aerial vehicle ground control station (GCS). The GCS issues an immediate alarm, triggers an automatic flight plan to a zone exhibiting unusual activity and departs without operator interaction. Crude petroleum theft constitutes the predominant form of oil loss, occurring principally at storage depots and tanker vehicles before transportation through pipelines. The monitoring system is programmed to provide a range of contingency protocols that can guarantee the safety and protection of the pipeline inventory.

7. Ethical Considerations

The use of Big Data and AI in combating oil theft and in resource management raises important ethical issues that require careful attention. Protecting individual and group privacy constitutes a significant concern when gathering and analyzing large-scale data on supply chain operations. Holding the means of data collection and analysis places tremendous responsibility on those involved, and effective regulations and oversight are necessary to discourage misuse through bias or partiality (Ryan et al., 2019). Data collection techniques that involve personal devices create asymmetries in access to, and stewardship of, information, thereby undermining transparency and accountability (Sun Lim & Bouffanais, 2022). Large corporations routinely conduct data mining and algorithmic design in a manner so complex that regulators are unable to comprehensively assess potential violations. Commercial exploitation of such data may therefore proceed without appropriate safeguards in place, exposing users to unanticipated threats.

7.1. Data Privacy Concerns

Strategies empowering holistic data collection, acquisition, integration, processing, and analytics to support the exploration of certainties, uncertainties, and conditionals will have greater success when implementing privacy measures (Dabab et al., 2018). The unregulated use of Big Data analytics tools also increases opportunities for corporate profiling, which involves collating and analyzing sensitive personal information to identify potential market opportunities or customer trends. Information privacy protection concerns stem from the capability to access, aggregate, and analyze personal information, and it is therefore the degree to which data it is personally identifiable, sensitive, or protected that determines whether a message broker, such as Twitter, can share the information it has for marketing purposes. The generation of data is often uncontrolled and remains independent from data subjects, and individuals may have no understanding or knowledge of the extent to which their data is aggregated, or by whom. Robust privacy mechanisms characterized by transparency and control remain the key to safeguarding individuals and their data. Informed consent is a paramount component of Privacy by Design and derives from the larger concept of Fair Information Practice, which emphasizes transparency, notice, and choice as dominant principles.

7.2. Ethical AI Use

The application of Big Data and AI technologies may raise issues related to data protection and privacy along with operational risks and transparency. Ensuring the ethical use of these technologies is imperative to protect the interests of all stakeholders and society. The ethical questions concern the responsible application by state and non-state actors who may exploit these instruments, demanding robust technological support that addresses the challenge of ethical and unbiased deployment (Sun Lim & Bouffanais, 2022). One major social concern results from the potential loss of control associated with the autonomous decision-making of AI systems Type and by the invisible data collection and data processing of Big Data analyses. Scholars have outlined the main normative challenges of the ethical use of automated decision systems. These challenges encompass ethical responsibility, fairness and equality, transparency and explicability, individual and social well-being, and the continuity and buffer of human judgment. The widespread diffusion of digital technologies offers new opportunities to improve monitoring, detect illicit behaviours and prevent criminal activities (M. Salem et al., 2022) but invites the search for appropriate regulations that guarantee the responsible use of emerging technologies.

8. Conclusion

Oil theft—illegal acquisition of crude oil, refined petroleum products, petrochemicals, and natural gas liquids—damages economies and resources worldwide. The resilience of transnational organized criminals and corrupt officials intensifies the challenge. Legal methods for resource management, informed by accurate data on production and reserves, can better inform decisions on allocation.

Big Data and Artificial Intelligence (AI) offer promising avenues for detection and prevention. Digital oil fields combine sensors, communication networks, and data centers to collect, transmit, and record heterogeneous data, enabling intelligent strategies and rapid responses. Digital transformation relies on pattern recognition, time series analysis, social network analysis, content extraction, knowledge discovery, and SCADA systems (Lopes D'Almeida et al., 2022). AI supports production optimization and performance monitoring—including forecasting—through neural networks, fuzzy logic, support vector machines, real-time analysis, and Bayesian networks. Integration with multiphase-flow metering further enhances optimization. For artificial-lift systems, decision trees, support vector machines, Bayesian networks, and random forests aid failure detection and prediction; predictive maintenance of equipment also benefits from support vector machines and gradient-boosting trees. AI algorithms require extensive, diverse data sets to learn effectively and deliver accurate responses. In fields like geological exploration and production monitoring, machine learning identifies hidden data patterns, enabling enhanced reservoir characterization and dynamics prediction. Intelligent-production monitoring detects abnormal situations, forecasts output, and optimizes operations (Wang et al., 2024). Big-data analysis supports more informed decision making and management. Learning from accidents facilitates emergency-response planning—evidenced by Statoil's offshore safety monitoring and Shell's optimized refining for improved energy efficiency and product quality.

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